HONOLULU RAPID TRANSIT SYSTEM

Report on

WAIALAE AVENUE SUBWAY STUDY

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Parsons
Brinckerhoff

PARSONS BRINCKERHOFF QUADE & DOUGLAS, INC.

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REPORT SUMMARY

The study considers a transit subway 7,530 feet long between portals. Three line segments, 2,350 feet, 2,080 feet, and 2,260 feet in length and two stations with 420-foot platforms are included. Two alternative construction methods, cut-and-cover and tunnelling, were considered. The recommended solution is to construct the western line segment and the Sixth Avenue Station by cut-and-cover and the remainder by tunnelling.

Geologic information is minimal. The basic elements are two types of lava flows, the vesicular Kaimuki basalt overlying a denser Mauumae basalt, with the two separated by a relatively thin layer (less than ten feet thick) of volcanic tuff having rock-like characteristics. Based on aereal geology, visual observation, and six borings, the Kaimuki and higher elevations of the Mauumae are reasonably competent tunnelling media. The rock quality indicated by the borings is quite variable, but no extensive zones of poor quality have been identified. Explosives will be required for both tunnelling and cut-and-cover construction. Water is not expected to be a problem.

There are very few utilities along Waialae that will affect construction. Most are shallow. A utility reservation only five feet deep is considered sufficient unless there are plans for future major utilities at a deeper depth.

Maintenance of traffic will be a serious problem for the cut-and-cover alternative because of the lack of a paralleling street to the north between Saint Louis Drive and Palolo Avenue and between Tenth and Wilhemina. Special, twin, single-cell boxes can be used between First and Palolo to solve the problem there, but an acceptable solution between Tenth and Wilhemina is not apparent.

No special problems with a cut-and-cover alignment other than traffic maintenance have been found.

Line tunnelling is feasible and economical from the Sixth Avenue Station eastward 4,600 feet to the portal beyond Seventeenth. Construction of the Koko Head Avenue Station by tunnelling is feasible.

The comparative order of magnitude cost of the cut-and-cover alternative is approximately $36,000,000. The comparable tunnelling alternative cost is $33,000,000. for the conditions assumed. These figures do not include system-wide elements, utilities, right-of-way, escalation or contingency. Line tunnels are estimated to cost nearly 20 percent less than cut-and-cover construction. A mined station at Koko Head Avenue is estimated to cost the same as a cut-and-cover station there. A mined station is not recommended at Sixth Avenue.

I. WAIALAE AV. AND ENVIRONS

General

Waialae Av. is a major, heavily travelled, east-west arterial route within the study area. It is bordered by a mix of residential, commercial, and very light industrial buildings set at varying distances from the property lines. Most buildings are one or two stories in height; a few are three or four-story; the highest immediately adjacent to the street is a seven-story apartment building with its narrow side fronting Waialae.

While businesses are scattered along the street, there is a concentrated commercial area between Tenth and Thirteenth Avenues. Koko Head Av. is a major cross arterial and is located between Twelfth and Thirteenth.

Interstate Route H-1 crosses Waialae in cut east of Seventeenth. As a result, there is a complex of on and off ramps and street connections between Seventeenth and Twenty-first.

Harding St. is located one block south and is continuous through the study area. It is a narrow residential street, only 24 feet between curbs, and is incapable of taking a major traffic diversion from Waialae for the full construction period. A minor paralleling street, Mahina, extends from Koko Head to Fifteenth between Harding and Waialae. There is no continuous paralleling street to the north. The first street to the north, Keanu, is a broad street extending from Palolo Av. (which intersects Waialae between Fourth and Fifth) to Tenth. After a three-block hiatus, it resumes as a much narrower street running eastward from Wilhelmina (one block east of Koko Head).

Detail Description

The subway study covers a distance of about 9,000 feet along Waialae Av., from west of First Av. to east of Twenty-First Av. Eastward from First Av., at about Elev. 55, to near Tenth (4,100 feet), the grade is a rising 1.0 to 1.5 percent. The grade then steepens to approximately three percent for about 900 feet to near Twelfth where an essentially flat crest at about Elev. 181 extends about 200 feet. Beyond Twelfth, the grade is a descending grade of approximately three percent to Fourteenth where it reduces to less than two percent and

and eventually becomes essentially flat from Sixteenth to Seventeenth, which is approximately 7,200 feet from First Av. and is at about Elev. 124.

East of Seventeenth, Waialae Av. becomes complex. The eastbound lanes continue over the H-1 Freeway, join a freeway off ramp, and then divide into an on ramp and a descending surface street to Twenty-First Av. at about Elev. 55. Westbound from Twenty-First, Waialae remains north of the freeway, first dividing for an on ramp and then joining an off ramp before reaching Seventeenth. The distance from Seventeenth to Twenty-First is about 1,500 feet.

Between First and Seventeenth, Waialae varies frequently in widths between property lines and curbs. Property lines are from 70 to 90 feet apart; the paved width ranges from 44 feet to 72 feet. The north side dimensions are uniform at 32 feet paved and 40 feet from centerline to property line for the 5,200 feet from First to Koko Head Av. After a short length of setback to Wilhelmina, these dimensions become 22 feet and 35 to Seventeenth. The south side has 22 feet paved and 30 feet from centerline to the property line for the 3,600 feet from First to Ninth (a short section east of Seventh is wider). From Ninth to Tenth, these dimensions are 32 feet and 40 feet, Tenth to Eleventh 40 feet and 50 feet, then 32 feet and 40 feet to Thirteenth, 22 and 35 to Fourteenth, and 22 and 40 for the remainder of the distance to Seventeenth.

Two stations are planned. The Sixth Avenue Station has been located for the purposes of this study in the 450 feet between Sixth and Seventh Avenues. The site is bordered on the south by St. Patrick's Church, well set back from the street and with extensive parking front and rear. Aliiolani Elementary School, which has considerable open space with buildings set back somewhat from the street, occupies the north side. The distance between property lines is 70 feet, between curbs 54 feet.

The second station, Koko Head Avenue Station, is in the heart of the local business district. Buildings are set on the property lines, which are 80 feet apart. The distance between curbs is 64 feet. The station has been approximately centered on Twelfth Av. (which extends south only from Waialae) and extends just across both Center St. (running north only) and Koko Head Av.

If advisable for patronage reasons, the Sixth Avenue Station can be sited one block west, between Fifth and Sixth Avenues where the Sacred Heart Academy is set well back on the south side.

II. UTILITIES

General

In many U.S. cities, utilities are a major constraint in subway construction. Waialae Av. is a pleasant exception. In general, there is a zone 40 feet wide along Waialae that is free of utilities. The sewers are generally back of the curb lines. Primary crossing utilities are gas, water, and telephone and these are very shallow, less than four feet below the street surface. Crossing storm drains are generally less than five feet deep. Major exceptions are noted later. This general lack of interfering paralleling utilities combined with shallow crossing utilities make possible a very shallow utility reservation (unless deeper utilities are already planned), with attendant economy for cut-and-cover construction.

Specific Utilities

The most important utility conflict is the 5-ft. by 7-ft. sewer running north on Second, west on Waialae, and north on Saint Louis Drive to Palolo Stream. Its invert is 33 feet below the surface at Second and 24 feet at Saint Louis. Retaining and supporting the sewer in place would result in excessively deep subway cut-and-cover construction in an unfavorable geology. There are two solutions. One is to reconstruct the sewer at a reduced gradient on the south side of Waialae beginning at Second and continuing it to beyond First where it can pass beneath the offstreet transit structure. If, as understood, the tunnel houses only a small sewer line (8 inches), the second, and preferable, solution is to relocate the sewer slightly north, adjacent to the cut-and-cover construction. The sewer invert appears to be sufficiently deep at Second Av. that the subway can pass over the small line.

A 24-inch water main lies in the center of Waialae between First and Palolo Avenues (to near Fifth). This is assumed to be four feet deep, or less, and, if necessary, will be supported in place during cut-and-cover construction.

A four-inch gas main lies within the cut-and-cover zone from about Ninth westward to Seventeenth and must be rerouted during construction.

A system of 18 and 24-inch storm drains cross Waialae at Fourth, Fifth, and Sixth, extend along the north side of Waialae, and go a short distance into Palolo. The outlet is assumed to be into Palolo Stream. A depth of five feet is indicated at Sixth. The topography warrants the assumption it is not deeper elsewhere in the construction zone.

Other 18-inch storm drains cross Waialae at less than five-foot depth at Tenth, Thirteenth, and Seventeenth.

A 12-inch sewer crosses Waialae at Sixth at about four-foot depth. This apparently flows northward in Sixth.

Sewers, 8 to 12 inches in diameter, cross Waialae at Sixth, Ninth, Eleventh, and Seventeenth. All but the one at Ninth appear to have inverts only four feet below grade; that one is 5.5 feet below grade.

<u>Summary</u>

Relocation of the sewer between First and Second permits establishing a minimal utility reservation of five feet unless there are plans for future, deeper utilities. Due to subway profile, the sewer at Ninth will not be a constraint.

III. GEOLOGY

Introduction

Geologic information suitable for evaluation of subway construction along Waialae Avenue is minimal. At the time this report was drafted, there was no geotechnical data available. Boring data from six boreholes spaced from 1,000 to 2,300 feet apart became available only at the end of the review period.

Geologic Description

The geologic information originally available for Waialae Avenue is described in the Dames & Moore letter of June 9, 1978, to Daniel, Mann, Johnson & Mendenhall of Hawaii. The generalized stratigraphy, from the surface downward, consists of residual soil, Kaimuki basalt, Diamond Head Ash, alluvium (discontinuous), and Mauumae basalt. A ridge of Koolau basalt presumably underlies the Mauumae in the vicinity of Koko Head Avenue. Descriptions of the formations and the pertinent material from that letter are quoted below.

"1. Kaimuki Basalt - Kaimuki basalt is believed to have originated from the last volcanic activities along the rift zone (Kaau Rift Zone) that stretched from Diamond Head to the tip of Palolo Valley. Generally, the Kaimuki basalt is overlain by a few inches to several feet of reddish brown silt believed to be residual soils. A 4-inch layer of the same soil was found sandwiched in rock at about 5 feet below the rock surface in some areas. The Kaimuki basalt generally is very vesicular olivine pahoehoe rock. Frequent lava tubes and cavities are expected. However, in some places, the Kaimuki basalt consists of very thick massive layers with cooling cracks forming irregular blocks. The fresh rocks are generally very hard while clinker and more vesicular rocks are moderately hard.

"2. Diamond Head Black Ash or Tuff - The Diamond Head ash resulted from the deposition from eruptions of Diamond Head volcano. The ash, or tuff, underlies the Kaimuki basalt in several areas. The areas underlain by ashes are most likely located between Kapahulu Avenue and Tenth Avenue, and also east of 15th Avenue. The hardness of the Diamond Head ash, or tuff, probably vary from soft to relatively hard.

"3. Mauumae Basalt and Cinder - Mauumae basalt and cinder originated from the Mauumae vent which is located 1½ blocks north of Waialae Avenue between Sierra Drive and Koko Head Avenue. The Mauumae basalt is hard nepheline-melelite basalt and generally underlies the Kaimuki basalt and, in places, the Diamond Head ash, with occasional soil between the Diamond Head ash and Mauumae basalt. It is believed that the Mauumae volcano erupted while the sea level was 70 to 100 feet above the present sea level. Therefore, rough, hard pillow basalts are expected below an elevation of, say, 70 feet. The Mauumae basalts are difficult to excavate and to support in tunneling work because of the lumpy nature of the underwater solidification of basalt and its hardness.

" Mauumae cinder probably constitutes major deposits near its vent. The cinder probably was deposited throughout the Mauumae volcanic activities. It is believed that the bottom of the Mauumae cinder probably extends somewhat below the present sea level beneath Waialae Avenue.

"4. Alluvium Deposits - Below the above volcanic rocks and cinders, alluvium soil deposits are expected. Alluvium deposits generally consist of clay, silt, sand and boulders. Boulders are perhaps more frequent near the walls of Palolo Valley, and east of Koko Head Avenue. A silty alluvium cinder sand deposit should be expected toward the junction of Kapahulu Avenue and Waialae Avenue.

"5. Residual Soil - Generally, there are several occurrences of stiff reddish-brown silts overlying Kaimuki basalts. It is also found sandwiched within Kaimuki basalt itself. These soils are believed to be residual soils derived from the weathering of basalts. The occurrence of these soils is believed to be irregular. The thickness may vary from a few inches up to several feet.

" It is believed that the groundwater system in the Mauumae, Kaimuki and Diamond Head basalts is generally of localized perched water above the old alluvium deposits. The groundwater is believed to react quickly to local rainfalls, because the local geologic units are generally very pervious to the infiltration of water.

" The borings drilled for H-1 freeway were relatively shallow and did not, in most cases, penetrate through Mauumae basalt. Only a few boring logs are available along Waialae Avenue. Thus, data on actual thicknesses of various geologic units described above are relatively scarce along Waialae Avenue."

In addition to the above, visual examination of the outcroppings were made along Sierra Drive for the Mauumae basalt and back of the Fire Station facing Koko Head Avenue south of the Freeway and in the Freeway cuts in the same area for the Kaimuki basalt. Both have been compared with outcrops of the better known Koolau basalt.

The specific results of the six borings made by Walter Lum Associates, Inc. and reported in a letter to Daniel, Mann, Johnson & Mendenhall of Hawaii, dated January 5, 1979, both confirm and refute the geology inferred by Dames & Moore. The generalized stratigraphy is confirmed. However, the Diamond Head Ash (apparently locally called mud rock) is now more correctly designated as volcanic tuff because it has soft to medium rock characteristics. In addition, there is good reason (both specific and interpretive) to believe this volcanic tuff is a continuous layer separating the Kaimuki and Mauumae basalts throughout the study area. However, the alluvium underlying the volcanic tuff was found only in the borehole at Seventh Avenue. This lends credence to the postulation that in ancient times Palolo Valley was a depression between, say, Fourth and Tenth. Water was encountered only in the borehole at First Avenue; its elevation was below the cut-and-cover construction invert and about at what would be tunnelling invert.

The Lum borings are of special significance for the tunnelling alternative because the RQD's (Rock Quality Designation) of the rock cores were determined. Used properly and carefully, RQD can aid the tunnel engineer in evaluating the adequacy of the rock for tunneling. Values ranged, not unexpectedly, from 0 (exceedingly poor) to 100 (excellent) for both rock types.

A few minor voids and thin clinker beds were evident in most boreholes. The voids did not appear to be more than one foot in height nor the beds more than two feet thick.

Engineering Evaluation

The surficial layer of residual soil is considered too thin to have any significant effect on cut-and-cover construction. For tunnelling, the three to five feet immediately below the ground surface have been discounted in arriving at minimum tunnelling depths.

The presence of rock for nearly the full depth of cut-and-cover excavation is not favorable for that construction method. While much of the rock probably can be excavated with earthmoving "rippers", much will also have to be blasted. Such blasting in an urban area must be carefully controlled to protect persons and property in the adjacent areas. While both ripping and blasting pose no unusual construction problems, they will result in higher costs than normally expected for cut-and-cover construction.

The Kaimuki basalt is considered a moderately competent tunnelling medium, inferior in quality to the Koolau, but suitable in most areas for shotcrete and rock bolt reinforcement. The predominant features of the formation is the vesicular (puka-puka) nature of this pahoehoe type lava, at least in the upper flows, the layering of the frequently thin flows, and the extensive but random fracturing of the thicker flows. The fractures are rough, irregular, and generally open, but do not appear to be continuous across successive flows. The open, unhealed nature of the fractures would be of considerable concern were it not for their roughness and discontinuity. The rock mass is visualized as consisting of interlocking blocks of intact rock. Only a few thin clinker beds and small cavities were found in the boreholes. For the purposes of this report, it is assumed they are not significantly detrimental. Their presence, however, together with the highly variable RQD and open fractures, indicates pretensioned, mechanically anchored, cement grouted, rock bolts may be required rather than untensioned resin grouted rock dowels.

The boring program changed the original evaluation of the Diamond Head Ash. As a volcanic tuff, it now appears to be a reasonably competent tunnelling medium. In one instance, its RQD was superior to those in the surrounding basalts. First hand experience with a South American tunnel in a massive, presumably similar material is encouraging; that material was very low in strength, yet a two-lane highway tunnel was driven through it without difficulty using shotcrete and rock bolts for support and reinforcement. How the relatively thin layer of tuff will interact with the basalts is not known, however.

As a result of the boring program, it does not appear that the alluvium, due to its location, will be a significant factor in construction. More detailed information is necessary, however.

Visual observation of the Mauumae and the results of the borings indicate it can be a satisfactory tunnelling medium. Its aa nature tends to make it superior to the Kaimuki above, say, Elevation 90.

The Mauumae volcanics east of Fourth Avenue remain essentially unknown. The formation most likely was deposited under water here with unknown interstitial filling between the pillow basalts. The borings indicate an excellent hard rock at Fourth Avenue but a very poor material at First Avenue. The uncertainties here are considered sufficient to eliminate tunnelling from consideration, at least for the present.

The Mauumae also may be encountered in the tunnelling alternative in the vicinity of Koko Head Avenue Station and also to the east. Deposition here was above sea level and, therefore, the formation should not pose special problems. A clinker bed was located within the Mauumae in the borehole at that station.

The RQD's determined in the borehole at the Koko Head Avenue Station indicate it is desirable to raise the station invert about ten feet from that shown on the tunnelling alternative profile to take advantage of superior rock for the station arches.

Groundwater based on information to date is not considered to be a problem. If encountered in tunnelling, it is likely to be perched and not large in quantity. Water in cut-and-cover sections can be handled conventionally.

Summary

The quality of the rocks underlying Waialae Avenue is extremely variable. Despite the variation, tunnelling is considered a suitable construction method between Fourth and Seventeenth Avenues. The volcanic tuff separating the Kaimuki and Mauumae basalts does not appear to be an adverse formation. West of Fourth, the unknowns and probably deteriorating conditions toward the west make further consideration of tunnelling inadvisable at this time. The presence of the rock and need for considerable blasting in confined trenches makes cut-and-cover construction more difficult and costly than in a soft-ground stratigraphy.

IV. CUT-AND-COVER CONSTRUCTION

General

The typical cut-and-cover construction of a subway beneath a street on which traffic must be maintained involves two complete closures of the street, the first for three or four months in a given zone and the second for at least two months; and a long period (on the order of a year in line sections and two years at stations) of slow and difficult traffic operation on a temporary wooden deck between the closure periods.

It is the above adverse impact on traffic, rather than the direct construction cost, which generally triggers a study of alternative construction methods, including tunnelling.

Typical Procedure

In a congested street, the first cut-and-cover operation frequently is a relocation of utilities to the extent possible to a location outside the excavation area. The time for this may be a year. Waialae Avenue, having only minimal utilities in the excavation zone, will not be subject to this disturbance in advance of complete disruption.

The next step is to close two lanes of traffic a block at a time while holes are drilled and soldier piles installed. These piles provide support for the trench walls and for the street decking during construction.

Next is complete closure of the street for several blocks at a time in order to excavate the utility layer, place the steel cross beams and wooden decking surface, and support the utilities from the deck structure. Five such closure areas would occur consecutively along Waialae.

After the deck is installed, limited traffic (no heavy trucks) is allowed on the decked street. Excavation followed by construction of the subway structure then occurs beneath the decking. If the subway box is deep, backfill up to the utility zone will be placed beneath the deck.

Finally, the street is again closed while backfilling, bedding of the utilities, and repaving of the street is performed. The street is then again opened to traffic.

Inverted Construction

The most frequently suggested alternative to the typical cut-and-cover procedure, other than tunnelling, is a variant called "Inverted" (or, top-to-bottom) construction. It is rarely used in the United States. However, the geology underlying Waialae Avenue makes this method a prime candidate for this location.

The initial street closure is still required. An additional month may be required during this closure, but the long period of reduced speed traffic on a rough decked street and the second street closure are avoided. Also, the initial partial disruption for installing soldier piles probably can be avoided in Waialae Avenue.

Using this procedure, the street would be excavated to deck or box roof level and high early strength concrete grade or abutment beams is poured outside the neat excavation lines. Two lines of inclined rock bolts would be installed along each abutment and grouted to unify the rock immediately outside the future excavation. Pre-cast beam-panels, perhaps as large as 38 feet wide (transverse to Waialae) by 10 feet long would be installed on the grade beams and beneath the utilities in the street. To reduce initial (transport) panel weight, a second pour of unreinforced concrete would be placed in large pockets in the panels. These panels serve two functions. During construction, they support the backfill and final street surface. They also form the final roof of the subway structure. While much more work is involved during this construction stage, the overlapping nature of the separate activities minimizes the additional street closure time.

This procedure has the definite advantage of reducing impact on traffic and businesses in the area. It will probably cost slightly more than the typical cut-and-cover method, but the difference will be considerably less than the accuracy of the estimating in this report. Unfortunately, the method still requires a complete closure of consecutive portions of Waialae for a period of time and, therefore, requires a complete rerouting of all traffic during that interval.

Special Method for Waialae

The rock immediately beneath Waialae Av. makes possible a variant of either the typical or the inverted form of cut-and-cover construction which will make possible limited use of Waialae at all times. This obviously reduces substantially the effect of construction on traffic.

The traditional cut-and-cover subway structure is a single two-cell box; for HART, the box would be 35 feet wide. It is proposed, instead, to use two separate, single track, single-cell boxes wherever necessary to reduce traffic dislocation. The procedure is required from First to Palolo Avenues and may, with further study, be the preferred solution throughout the line sections. (However, paralleling side streets on both sides of Waialae reduce the traffic maintenance problem east of Palolo, except between Tenth and Wilhemina.)

A single track box structure would be about 18 feet wide. This would permit maintaining two lanes of traffic on one side of the construction area around the area where the surface would be excavated and the subway roof installed. Appreciable further study of traffic patterns and construction requirements and techniques might well result in permitting this smaller excavation to remain undecked for the full construction period.

A continuous pillar of rock between the subway boxes would be left in the center of the street. Future widening of Waialae on the south side of the street is planned in various locations. Coordinating this widening with the subway construction would facilitate use of this special method and would result in maintaining a third lane of traffic through the area. A schematic cross section of this variant is included in the section describing the cut-and-cover alternative.

For some years, concrete water transmission pipes have been precast in diameters large enough for subways. In recent years, large rectangular box culverts have been similarly precast. The use of this technique could effectively reduce the time the excavation is open in Waialae Av. If further geotechnic exploration confirms the results of the six borings already taken, namely that the ground water table is below cut-and-cover invert elevation, this procedure should be given serious consideration.

Use of this method may or may not make use of center platform stations more appropriate than side platforms. This is less likely in the relatively open area of the Sixth Av. Station, but is more likely in the congested area for the Koko Head Av. Station.

Summary

If the Waialae Av. subway is constructed by cut-and-cover methods, this very brief study indicates the use of two single track boxes from First Av. to be feasible and necessary. The Sixth Av. Station most likely would be constructed in the traditional way, closing the street twice and using a decked-over excavation to permit nearly full traffic flow between the closures. East of Sixth, two boxes could also be used, if detailed analysis of traffic maintenance requirements so dictate. Full street decking and conventional construction is likely at that station. A single two-cell box appears most appropriate east of that station.

V. CUT-AND-COVER ALTERNATIVE

General

The cut-and-cover subway alternative set forth below has been developed as a result of the geology, the existing street pattern, and the arterial traffic nature of Waialae Av. The plan and profile for the alternative are shown in Figures 1 through 4.

Alignment

The western, or Ewa, portal is located just north and west of the intersection of First and Waialae. The portal is offstreet, about 200 feet west of Saint Louis Drive, on a diverging horizontal alignment. A vertical curve in this area transitions from a descending 3.5 percent grade to an ascending 2.8 percent grade. A drainage sump will be located at the low point of the profile.

Between First Av. and a point near Fifth, the trackways will be carried in two separate single cell boxes spaced about 32 feet apart on centers. Flat reversing curves (5,000-foot radius) then will close the spacing to the minimum required for a side platform station. A utility reservation depth of five feet will be maintained here and throughout the length of the subway. The trackways will be at an average depth of 24 feet below the surface between First and Sixth. Figure 5 shows a schematic cross section in this area and indicates how partial traffic flows can be maintained at all times in this zone.

Vertical curves each side of Sixth Avenue Station will transition to and from a rising one percent station gradient. The station will have only one level, the platform level, but there will be a cross connection between platforms below the trackways. The platforms will be about 20 feet below the street.

Between the Sixth Avenue and Koko Head Avenue Stations, the trackways will remain closely spaced on a rising 1.9 percent grade and will be at an average depth of 28 feet below the surface.

Due to the steep street gradients on both sides of Twelfth and utility reservation "hinge points" at about Tenth and Fourteenth, the Koko Head Avenue Station will be relatively deep, permitting a conventional two-level station. The platforms will be 44 to 48 feet below the street surface. Vertical curves each side of the station will transition to a rising 0.2 percent station gradient. The station will be located beneath Center, Twelfth, and Koko Head Avenues.

East of Koko Head Avenue, the profile will be a descending 1.65 percent grade to about Sixteenth, where a vertical curve will transition to a rising 4.0 percent grade. A drainage sump will be required at the low point. The portal will be in mid-street between east and west bound lanes east of Seventeenth.

Some property takes on the north side of Waialae will be necessary east of Sixteenth in order to shift the west bound lanes northward to accommodate the mid-street portal. Alternatively, the alignment could be north of the present Waialae lanes in this area, but this would require an aerial structure over the west bound lanes. About the same amount of property would be required in either case, but the mid-street portal avoids the use of a considerably higher structure over the Freeway.

The horizontal alignment shown in Figure 4 involves swinging the alignment northerly east of the subway portal, generally along the present west bound lanes. These lanes will have to be shifted northerly, with consequent additional property takes. The alignment then crosses over the H-1 Freeway on rather sharp reversing curves and then runs alongside the Freeway and immediately to the south.

An alternative horizontal alignment is shown on the tunnel plan and profile, Figure 9. In this case, the horizontal alignment remains close to and north of the east bound lanes but rises considerably higher in order to pass over those east bound lanes and a freeway on-ramp before returning to the plan and profile of the other alignment east of Hunakai Street.

Both alternative alignments have advantages and disadvantages. The northerly one has a low profile, but is speed restricted. The northerly one is not speed restricted but requires a high aerial structure. The choice, then, is speed restriction and low silhouette versus design speed and high structure for community acceptance.

Construction and Traffic Maintenance

Between First and about Fifth, two separate single track box structures will be used. One box at a time will be constructed in order to maintain at least two lanes of traffic on Waialae between First and Palolo, where there is no paralleling street to the north. To do otherwise would result in intolerable traffic maintenance problems. Three lanes can be maintained with temporary or permanent widening of the street in this area. Additional studies will be required to determine whether an inverted or an open-braced trench form of construction should be used.

Conventional cut-and-cover techniques will be used for the Sixth Avenue Station and for a short distance to the west. During the two street closure periods, traffic can be rerouted both north and south of Waialae on paralleling streets or possibly on temporary easements around the excavation.

From Seventh to Tenth, the inverted method will be used to construct a single two-cell subway structure. Again, traffic during the closure period will be diverted both north and south, but only one closure period will be required.

Construction impact will be greatest between Tenth and Thirteenth because of the lack of a paralleling through street to the north. The generally 64 feet between curbs (72 feet between Tenth and Eleventh) will permit keeping one lane of traffic open at all times. However, the 52-foot pavement width for the 320 feet between Thirteenth and Wilhelmina will probably result in a complete closure unless the north side of Waialae is reconstructed. Diverting traffic to both Harding and Keanu may make this closure tolerable. Additional studies will be required to determine if an additional line of soldier piles down the center of the street and station is feasible in order to close only one side of the street at a time in the station area, thus maintaining partial traffic through the construction zone. The gross traffic disruption and the disruption to the concentrated business district are sufficient reasons for recommending the tunnelled alternative in this area. Fortunately, that alternative also is more economical.

Between Thirteenth and Seventeenth, the street is only 44 feet wide between curbs. However, the presence of paralleling streets north and south make closure of Waialae feasible while constructing the "hat" for the construction of the two-cell box by the inverted method.

Widening of Waialae east of Sixteenth and relocation of the west bound lanes should be completed before constructing the remainder of the subway in open trench east of Sixteenth.

Details of the construction between Seventeenth and Hunakai, while posing serious problems, can be developed but are not considered to impact on the subway construction.

Stations

The two stations will be conventional side platform stations. Sixth Avenue Station will be quite shallow, permitting only a single station level. Minimum width platforms (10 feet, except at the entrance) will result in an overall basic station width of only 48 feet. Vertical access to the platforms will be provided on each side of the street, outside the basic station box. Nominal property takes will be required for the entrances.

The shallow depth of Sixth Avenue Stations raises the possibility of a semi-open station where a little imaginative architecture could result in a station open to the south with perhaps a parking deck for church usage at street level. Such openness would relieve the tedium of the conventional subway station.

Detailed station patronage and operations studies may indicate the station more properly should be located between Fifth and Sixth Avenues. This can be done without significantly altering the station or the direct construction costs.

Koko Head Avenue Station, being deeper, can have a concourse level, facilitating circulation. An entrance arrangement similar to that proposed for the tunnelled station alternative would avoid the need to take private property. The concourse need extend over only one-third or less of the station, permitting spacious, high-ceiling station ends.

Except as described above, the two stations will be similar to other HART subway stations. Accordingly, plans and sections have not been developed for this brief study.

VI. TUNNEL CONSTRUCTION

General

The principal difference between tunnelling and cut-and-cover construction of subways, insofar as the public is concerned, is the tremendous decrease in disruption to community activities, especially traffic, of the tunnelling method compared to the cut-and-cover method. Generally, the direct cost of tunnelling is greater than for cut-and-cover. The indirect cost of community disruption caused by cut-and-cover methods is difficult to evaluate monetarily. When conditions are suitable for tunnelling, as they are along much of Waialae, the selection of method becomes a matter of evaluating the cost differential in terms of community benefit resulting from decreased disruption.

Much of the community benefit derived from tunnelling is lost if stations are constructed by cut-and-cover methods and only the line between stations tunnelled. It is much more difficult to tunnel, or mine, a station, primarily because the substantially increased width of tunnel requires considerably better ground conditions and substantially more "cover," or distance from the tunnel crown (top) to the street surface.

The section on costs shows the Waialae Avenue Subway to be a remarkable exception to the above generality. The tunnelled alternative is actually cheaper in direct construction cost than cut-and-cover. The benefits to the community then are an asset of the most economic construction method.

Tunnel Portals

The approach to a tunnel portal is constructed in the same manner as for cut-and-cover construction. The primary difference is that the excavation must be deeper to provide a greater distance, on the order of the width of the tunnel, from the ground surface to the tunnel crown whereas only the depth of the utility reservation is needed in cut-and-cover. Community disruption is about the same for the two methods in the portal area. When the portal is off-street, as at the Waialae Ewa portal, the effect in either case is minimal.

Once mining begins, the only noticeable effect on the community is the hauling of material to the portal and hauling of tunnel "muck" (excavated material) from the portal. Minor disruption also occurs where ventilation shafts are required between stations. With line segment lengths of 2,400, 2,100, and 2,200 feet, such shafts may not be needed along Waialae. Ventilation shafts at each end of each station will be required, however.

Tunnelling Equipment

Actual construction methods are dependent on geologic conditions. In rock, either "drill and shoot," which involves the use of explosives, or mechanical excavation are the common procedures. The choice of method is dependent in part on the length of tunnelling involved, in part on the cost of mechanical equipment, and in part on the rock conditions. A full-face or tunnel boring machine (TBM) will cost at least $2,000,000, which must be written off on the project involved because of the current lack of standardization of tunnel sizes. Partial face machines, commonly called road headers in civil construction and continuous miners in the mining field, are less expensive, but their use is limited to rock in the softer ranges, say less than 15,000 psi of compressive strength, which is only half the typical strength of basalt. Finally, the extreme variability of the rock beneath Waialae, as evidenced by the borehole results, indicates that "drill and shoot" is the likely solution. It is impractical, however, in the brief scope of this study and with the lack of precise geological information to make a final decision as to excavation method. Accordingly, the "drill and shoot" method is assumed.

The tunnel gradients required for the Waialae Avenue subway and the tunnel cross section selected both point to the use of rubber tired equipment. The drill jumbo will have two or three drills, one of which will also be used as a "stoper" to drill the holes for the rock reinforcement.

Special LHD units (Load-Haul-Dump) will be used to remove the muck from the heading, transport it to the portal, and dump it for transfer to the over-the-road hauling equipment (trucks).

Shotcrete (a pneumatically applied concrete with a maximum aggregate size of three-quarters inch) and mechanically-anchored rock bolts (one-inch diameter steel rods typically eight feet long in the line sections) are appropriate for the typical support system. (Actually, this is a rock reinforcement rather than a rock support system.) At the portals, and at other localized areas where incompetent rock may be found, structural steel sets will be used for rock support in conjunction with the shotcrete. The shotcrete equipment must be portable because the mix can be pumped only a limited distance without an excessive pressure drop.

Mining Procedure

Tunnelling is a repetitive three-step procedure. In the "drill and shoot" phase, the face (end of the tunnel being excavated) is drilled, explosives loaded into the holes, and the charge detonated. The broken rock is then mucked out. Finally, the support is installed. The process is then repeated. On the average, one complete cycle per eight-hour shift can be anticipated. Using an eight-foot "round" and typical three-shift operation results in an average advance rate of about 24 feet per day.

Mined Stations

Relatively few transit stations have been constructed by mining in the United States. In large part, this is due to relatively poor ground conditions beneath most major cities. It is also due to lack of precedent. No stations were mined for BART (San Francisco), only one is being mined for MARTA (Atlanta), but several have been and are being mined for WMATA (Washington). The increasing demand for minimizing community disruption is resulting in a greater use of tunnelling and more mined stations can be expected where ground conditions are suitable.

The generally high cost of tunnelling makes conventional type stations expensive to mine. The tendency in the United States towards making stations large and magnificent does not help. In order to reduce costs, the volume of these stations must be minimized. A very effective method of accomplishing this is to mine two "half" stations, that is to enlarge each line tunnel into a single track side platform tunnel. This concept has been used for the proposed mined station at Koko Head Avenue.

VII. TUNNEL ALTERNATIVE

General

The tunnelling alternatives set forth below have been developed as a consequence of the generally favorable geology along Waialae Avenue. The plan and profile for the alternatives are shown in Figures 6 through 9. The location of the six borings is indicated on these drawings, as well as the location of the volcanic tuff layer, inferred from those borings, which separates the Kaimuki and Mauumae basalts.

Alignment

For reasons discussed later, the same alignment (plan and profile) and construction is preferred between the Ewa portal and Palolo Avenue as for the cut-and-cover alternative. Between Palolo and Sixth Avenue, however, the tracks remain well separated, rather than converging, in anticipation of tunnelling east of Seventh Avenue.

The Sixth Avenue Station is in the same location as for the cut-and-cover alternative but in its preferred form has a gradient of only 0.2 percent to obtain the greater depth needed for tunnelling east of Seventh. The profile shown on Figure 7 assumes a somewhat unusual side platform station with the platforms 27 to 32 feet below the street level. It is likely a center platform will eventually be selected; this would require lowering the platform and profile grade line about four feet in order to provide for the partial length concourse level. This station is discussed in more detail later.

Between the Sixth Avenue and Koko Head Avenue Stations, the trackways will be spaced about 31'-0 on centers and will be in single track tunnels on a rising 1.9 percent grade. The profile grade line is generally maintained at least 35 feet below the ground surface to provide about 20 feet of cover over the tunnels to insure the integrity of the rock arch over the tunnel.

A minimum drainage gradient of 0.2 percent is used through the twin cavern, side platform, tunnelled Koko Head Avenue Station. Track spacing remains about 31'-0 on centers; the platforms will be 54 to 58 feet below the ground surface, and the profile grade line will be three feet below the platform.

East of the station, the single trackway tunnels descend on a 2.2 percent grade to a PVI at about Sixteenth Avenue with an ascending 4.0 percent portal grade to daylight slightly west of the portals for the cut-and-cover alternatives. Just west of Sixteenth, flat reversing horizontal curves (5,000-foot radius) will be used to reduce the track spacing to that used in the cut-and-cover alternative at the portal. The last 150 feet of subway will be cut-and-cover construction. A minimal cover of 15 feet over the tunnel crown is required for a short distance at Fourteenth Avenue; elsewhere the cover generally is 20 feet or greater. Relocation and reconstruction of the westbound lanes of Waialae will be required in the vicinity of the portal.

East of the portal, the alignment is the same as for the cut-and-cover alternative. However, an extended tunnelling alignment on a descending 3.3 percent grade to cross beneath the Freeway, followed by an ascending 2.7 percent grade to a portal at Twentieth Avenue with aerial structure eastward alongside the Freeway is also possible.

Drainage sumps will be located at the low points of the alignment.

Sub-Alternatives West of Sixth Avenue

Three profiles are indicated from the Ewa portal to east of the Sixth Avenue Station in Figures 6 and 7. The lowest is for an "all tunnelled" alternative. It is not recommended because tunnelling the Sixth Avenue Station does not appear warranted due to both the added direct cost of the station and the inadvisability of tunnelling in the Mauumae volcanics below about Elevation 80, as discussed in the Engineering Evaluation of Section III, Geology. The middle alignment, with a cut-and-cover station and tunnelling to the west, also is not recommended, for the same geologic reason.

Sixth Avenue Station

The solid line profile shown on Figure 6, with cut-and-cover to the west and tunnelling to the east, results in an unusual side platform cut-and-cover station. In order to provide the trackway spacing required for tunnelling to the east, a pillar of rock about 15 feet wide would be left between the trackways resulting in the appearance of single track stations. The out-to-out dimension of the station proper would be about 64 feet below a street having only 70 feet between property lines. The escalation and stair access shafts, then, would be largely on private property -- the church to the south and the school to the north.

While more study is required once the detailed geology is known, it is likely the Sixth Avenue Station eventually may be designed as a center platform station. To do so necessitates lowering the profile grade line another four feet or reducing the depth of the utility reservation in the street over the station. The station proper then would be 50 feet or less in overall width and any property take at the station entrances would be minimal.

A center platform station with a lowered profile grade line has been used in the cost estimate. Two configurations are possible, each costing about the same. The platform could be end loaded from Seventh Avenue with the platform stairs and two escalator units in echelon, the furthest unit reaching nearly to station midpoint. Alternatively, a centroidal loading could be used, again with stairs and escalators in echelon to permit using a minimum platform width of 20 feet to minimize construction costs. The upper level, or concourse area, would extend only about one-third of the station length, resulting in a very high ceiling over the end thirds of the platform. This would give the station a feeling of great spaciousness.

The center platform station would not affect tunnelling costs to the east but, because of the increased depth, would increase cut-and-cover costs for about 300 feet to the west.

As discussed for the cut-and-cover alternative, the Sixth Avenue Station may be shifted one block west, to between Fifth and Sixth, if patronage and other studies indicate this is warranted.

<u>Koko Head Avenue Station</u>

A tunnelled station is especially appropriate for the business district at Koko Head Avenue. Heavy vehicular traffic in the 64-foot wide street, substantial pedestrian traffic in the eight-foot wide sidewalks, a deep profile grade line resulting from "hinge point" constraints in the topography that rises in both directions toward the station, and rock from almost the street surface downward, all favor the use of tunnelling as the construction method.

A mined station complex consisting of two single platform tunnels has been selected rather than a single, two-track cavern for three reasons. First, less cover is required, permitting the platforms to be closer to street level. Second, the competence of the Kaimuki basalt to maintain a single span of 50 feet is questionable. Third, the cost will be less.

The typical cross section of the platform cavern is shown in Figure 10 and the general layout and station access in Figure 11. The ten-foot minimum width platform is widened to 15 feet in a 75-foot centroidal area to facilitate passenger circulation. A crown height of 14'-6 above platform will provide a feeling of spaciousness. A series of arched openings in the rock pillar between platform tunnels will provide visual continuity between the tunnels and further the effect of spaciousness.

A single surface entrance is planned to eliminate the need for taking private property. Traffic on Twelfth Avenue at Waialae is nominal, mostly to and from the large, interior block parking lots which already have access to the adjacent streets. Eighty to 100 feet of the street can be closed without appreciable impact on traffic and used for the station entrance. An intermediate level landing provides access directly down to the Kahala-bound trains or, via a tunnelled passageway, to the University-bound trains.

Design-wise, the rock will be reinforced with rock dowels to aid it in supporting itself. A three-inch layer of shotcrete, bonded tightly to the rock, will further strengthen the rock arch and will prevent spalling of small rock fragments. A second three-inch layer will reinforce the first layer, act as a safety factor, and, with the addition of welded wire fabric within the layer, assure that no fragment of shotcrete will fall.

A wall of reinforced concrete will be used along the platform to protect people from the uneven, rough texture of the shotcrete surface. A similar wall will be used around the central rock pillars for architectural harmony. Leaving the shotcrete arch exposed will create a contrast, reduce noise by virtue of the uneven surface and texture, and express the inherent structural strength of the design.

Boring B-4 has indicated a layer of poor to fair rock immediately over the station crown. If additional borings indicate this to be a general condition over the station length, the profile should be raised about ten feet through the station. While the topographic "hinge points" at about Tenth and Fourteenth Avenues are constraints, this can be accomplished by using reversing vertical curves at each end of the station.

Tunnelling Alternative East of Seventeenth

Two profiles are shown between Seventeenth Avenue and Hunakai Street. One, the least cost, is aerial and is synonomous with the cut-and-cover alternative. Should there be serious objections to an aerial structure adjacent to and over the H-1 Freeway, a tunnelled alignment crossing below the Freeway is also feasible. The tunnel portal would be at about Twentieth Avenue and the transit structures would clear Twenty-First Avenue so that no change in traffic patterns would be required.

Summary

The recommended tunnelling alternative consists of cut-and-cover construction from the Ewa portal off-street near First Avenue to the Sixth Avenue Station and tunnel construction east of the station. Sixth Avenue Station would be a cut-and-cover center platform station. Koko Head Avenue Station would be a mined station with twin platform tunnels and a single surface entrance located off Waialae in Twelfth Avenue. The east portal is planned east of Seventeenth Avenue with aerial construction over the Freeway and then adjacent to it along its south side as the transit route continues east.

An alternative extension of the subway crossing under the Freeway and portalling at Twentieth is considered feasible.

Additional detailed geotechnic investigation of the alignment is essential to verify the assumptions made for the tunnelled alternative. Based on the six borings taken, these assumptions now appear valid.

VIII. COMPARATIVE ESTIMATE OF COSTS

Introduction

There is no data bank of subway costs in Honolulu because this type of construction does not exist locally. The budget and time schedule for this study has not permitted an in-depth evaluation based on local material and labor costs. As a result, unit costs have been developed based on two primary sources. One source is recent local highway bid prices for those items which are somewhat similar; extensive study has been given, for example, to the April, 1978, bid prices for the Keehi Interchange on Interstate Highway H-1. Concrete, reinforcing steel, asphaltic concrete, and base course prices are based on that project; in addition, the structural excavation prices have been used to evaluate excavation costs derived from other sources.

The other source of cost data is more difficult to apply with accuracy. The source is mainland cost data for very similar recent construction projects. These sources must be adjusted for escalation from bidding date and for traditional price differentials in construction costs among various metropolitan areas.

It should be remembered that the purposes of this study are, first, to compare the feasibility and merits of cut-and-cover and tunnelling methods of subway construction and, second, to obtain an approximate cost of each. The brevity of the study limits the estimate accuracy to order of magnitude range. The choice of construction method, however, can be made on a comparative estimate basis. This means that items which are estimated as a percentage of major cost items, e.g., escalation to midpoint of construction, contingency factors, and items common to both methods, e.g., system-wide elements, need not be included in the estimate.

Escalation

The United States once again is in the grips of uncontrolled inflation. The California Highway Index has increased nineteen percent from the third quarter of 1977 to the third quarter of 1978. The Bureau of Reclamation index for tunnel construction has increased eight percent within the year. The various Federal Highway indices have increased from sixteen to fifty-four percent in the same period.

The underground transit construction project used as a primary source of mainland data was bid in November, 1977. Based primarily on the Burec and FHWA quarterly indices, those prices must be increased at least fifteen percent to reflect current prices.

Geographic Indices

The principal non-Honolulu sources of cost data are San Francisco, California and Atlanta, Georgia. San Francisco is used because of its overall similarity of costs to Honolulu costs, Atlanta because of very detailed knowledge of a similar project. The 1979 Dodge "Guide to Public Works and Heavy Construction Costs" and the 1978 "Building Cost Data" by Means, provide a basis for geographic adjustments. These sources indicate Honolulu costs are one to four percent less than San Francisco, a differential that can be neglected. Labor rates are considerably lower in Honolulu, but the relative productivity factors tend to cancel a large part of the difference. Material costs are higher overall in Honolulu. Appropriate adjustments have been made to reflect differences between Honolulu and Atlanta costs.

Excavation Costs

Excavation costs account for approximately one-third of the estimated costs of the cut-and-cover alternative. It is imperative, therefore, that the excavation unit cost be as reliable as possible.

Local highway rock excavation costs cannot be used as a guide to subway construction costs in Honolulu. The fracture pattern in the lava flows control in each, but there the similarity ends. In a highway cut, much of the excavation can be done using rippers, a fairly economical procedure, especially in wide cuts. The side slopes permit a natural stepping-in or mini-benching between the successive flow layers. A subway cut is narrow by comparison, only about 35 feet wide at the base. More importantly, the excavation must have vertical sides when sited in a city street unless the street can be completely closed. These differences reduce the effectiveness of rippers and require the use of considerable blasting. The result is a substantial increase in unit costs. Decking the excavation to maintain traffic, a virtual necessity in Waialae Avenue, further complicates the excavation. Working space is reduced and the decking must be specially constructed and anchored in place. Carefully controlled blasting is essential, both to minimize damage to existing buildings due to vibration and to keep blasting overpressures down sufficiently that the decking will not be lifted bodily with each blast.

The Metropolitan Atlanta Rapid Transit Authority's (MARTA) Project CN 120 bid in November, 1977, has large volumes of rock excavation plus more than 60,000 cubic yards of trench excavations in soft ground, mixed face, and hard rock. The trench was decked over in various locations with 1,900 square yards of decking. The unit prices were $55 per cubic yard and $88 per square yard, respectively. Translated to Honolulu, these become current prices of $73 and $117, respectively. However, the Waialae excavation is five times greater than in Atlanta and the decking fifteen times greater so that some reduction is justified. Large timbers, the traditional decking material, are, however, the principal cost in conventional decking and are very expensive in Honolulu so that the decking reduction is not substantial.

After considerable study, excavation costs of $35 per cubic yard in the cut-and-cover line and $30 in the stations were used. There is concern, however, that the price for the deep excavation for Koko Head Avenue Station is too low.

A unit price of $110 per square yard for decking has been used. A lower price for wooden decking only would be justified. However, there is a mix of decking planned -- none for some single track boxes, timber in the station and some line areas, and concrete for the inverted method. The unit price indicated is very low for the last type since it is essentially a bridge deck. This is compensated for by assuming the same structural box section, regardless of decking, so that the total cost of inverted decking becomes the average decking figure plus the cost of the box roof.

Reinforced Concrete Costs

Reinforced concrete accounts for about half of the cut-and-cover costs. The reinforcing steel accounts for about 20 percent of the reinforced concrete cost in line sections and 30 percent in the stations.

The Keehi Interchange bid prices for concrete and reinforcing steel are considered good guides to the corresponding subway costs. Concrete for box culvert and drainage structures were bid at $250 to $270 per cubic yard and bridge concrete at $200 per cubic yard. Considering the restricted working conditions in the excavation, a price of $200 per cubic yard is realistic. Reinforcing steel bids ranged per $0.27 to $0.33 per pound, the latter for bridges. Again considering working conditions, $0.35 per pound is appropriate.

Reinforced concrete costs are less significant in the tunnel alternative, amounting to only 15 percent of the comparative cost of line sections and 40 percent in the tunnelled station. Concrete in the line sections is confined to the invert, where forms are unnecessary and an efficient production procedure can be developed. Accordingly, a price of $150 per cubic yard was used here. The relatively small work space in tunnels, use of arch forms in the passageways (but not in the platform tunnels), and generally more difficult working conditions resulted in using a price of $220 per cubic yard for station concrete. A price of $0.35 per pound was again used for reinforcing steel.

Tunnelling Costs

The previously referenced MARTA contract included 1,700 lineal feet of single track tunnel nearly identical to the section proposed for Waialae Avenue. The excavated cross sectional areas are the same; structural support consists of rock bolts and shotcrete and the invert slab is reinforced concrete. The unit price bid was $816 per lineal foot, complete. The equivalent current price in Hawaii would be $1,100. This price is considered too low because the Atlanta geology is an excellent, massive gneiss whereas the Waialae geology is a series of lava flows of varying thickness, density, partings between flows, and cooling fractures.

The cost of excavation for line tunnels is about half their total price, and somewhat less for the station. In the above MARTA contract there was, in addition to the line tunnels, 94,000 cubic yards of excavation for a mined rock station tunnel, broken into three categories: 71,000 CY "regular," 16,000 CY of "ancillary" (rooms and escalator, elevator, and air shafts) and

7,000 CY of difficult, multi-drift construction. Corresponding prices per cubic yard were $40, $77, and $106 respectively; these represent current Honolulu prices of $53, $103, and $141. Considering geological differences as well as quantities and techniques, an excavation price of $95 per cubic yard for the line tunnels and $80 and $110 for two types of station excavation are considered appropriate.

Concrete and reinforcing steel prices for tunnelled construction have already been discussed. The remaining primary items, shotcrete and rock reinforcement, are priced in accordance with prevailing mainland prices adjusted.

Comparative Estimates for Line Tunnels

The table below gives the quantities of primary items, their unit prices, and the cost per lineal foot of line structure for the two construction methods.

	Cut-and Cover (Two Tracks)			Tunnelling (Single Track)		
Item	Quantity	Unit Price	Cost	Quantity	Unit Price	Cost
Excavation, CY	40	$ 35	$1,400	10	$ 95	$ 950
Concrete, CY	8.0	200	1,600	1.15	150	173
Reinf. Steel, Lb.	1400	0.35	490	140	0.35	49
Shotcrete, CY	--			0.70	400	280
Rock Bolts, LF	--			20	12	240
Decking, SYd	4	110	440	--		
Backfill, CY	17	7	119	--		
Base Course, CY	1.3	17	22	--		
Asph. Concrete, T	1.3	35	45	--		
			$4,116		(One Track)	$1,692
Total Per Route Foot, System-wide elements not included		(Say)	$4,100		(Two Tunnels, Say)	$3,400

The cut-and-cover excavation and backfill quantities given above are based on the average depth of excavation between the Sixth Avenue and Koko Head Avenue stations of 31 feet. Between First and Sixth, the average depth is only 27 feet;

the route foot cost should be reduced $200 per route foot in this reach. Between Koko Head Avenue and the portal east of Seventeenth, the average depth is 33 feet; accordingly, the cost should be increased $100 per route foot.

The cost of two single track cut-and-cover boxes will be $400 per route foot more than for a two-cell box at the same profile grade elevations because of increased quantities and a slightly higher unit cost of excavation due to decreased work space. This form of construction is required from First to almost Sixth in order to maintain limited traffic in Waialae between First and Palolo.

Comparative Estimates for Stations

The table below gives the quantities, unit prices, and item costs for the cut-and-cover stations.

		Sixth Avenue		Koko Head Avenue	
Item	Unit Price	Quantity	Cost, $	Quantity	Cost, $
Excavation, CY	$ 30	28,000	$ 840,000	55,000	$1,650,000
Concrete, CY	200	7,200	1,440,000	9,400	1,880,000
Reinf. Steel, T	700	650	455,000	850	595,000
Backfill, CY	7	5,000	35,000	17,000	119,000
Decking, SYd	110	2,800	308,000	2,900	319,000
Base, CY	17	1,100	18,700	1,100	18,700
Asph. Concrete, T	35	800	30,800	900	31,500
TOTAL			$3,127,500		$4,613,200

The profile grade line depth below the surface averages only 24 feet at the Sixth Avenue Station, but averages 50 feet at Koko Head Avenue Station. The increase in cost as a cut-and-cover station is forced deeper into the ground is all too obvious.

The quantities and cost of a tunnelled station for Koko Head Avenue are as follows:

Item	Quantity	Unit Price	Cost, $
Excavation - standard	20,000 CY	$ 80	$1,600,000
- special	1,500 CY	110	165,000
- cut-and-cover	7,000 CY	50	350,000
Shotcrete	850 CY	400	340,000
Rock Dowels	25,000 LF	8	200,000
Rock Bolts	30,000 LF	10	300,000
Concrete	6,200 CY	220	1,364,000
Reinforcing Steel	1,000,000 lb.	0.35	350,000
Backfill (12th Ave.)	3,000 CY	7	21,000
Base	400 CY	17	6,800
Asphalt Concrete	300 T	35	10,500
Total			$4,707,300

Considering the accuracy of estimating, the above cost is the same as for a cut-and-cover station at the same location. The cost of a tunnelled station at Sixth Avenue would be the same as at Koko Head Avenue, or 50 percent more than on the cut-and-cover alternative because it must be deeper to permit tunnelling east of the station. In addition, there will be an increase in the cut-and-cover costs west of the station because of the need to use two single cell boxes to maintain the track spacing required for tunnelling to the east. The increased cost would be $550,000 for a center platform station. The increased line cost would average $800 per foot for two single cell boxes somewhat deeper than for the cut-and-cover profile over the required 300-foot length, for a total increase of line cost of $240,000.

Comparative Cost Totals

Summing the above and rounding, the total comparative costs for the two alternatives are shown in the table below.

	Cut-and-Cover	Tunnel
Line, 2,350 feet, Portal to Station	$10,100,000	$10,100,000
Add for Track Divergence	---	200,000
Sixth Avenue Station	3,100,000	3,700,000
Line, 2,080 feet, between Stations	8,500,000	7,100,000
Koko Head Avenue Station	4,600,000	4,700,000
Line, 2,260 feet, Station to Portal	9,500,000	7,000,000
Total for 7,530 feet, System-wide elements not included	$35,800,000	$32,800,000

The above figures are for the construction of subway structures and surface restoration only. They do not include the station architectural finishes, or portal construction. A credit of $700,000 has been taken in the line tunnel for the 230 feet of reduced distance to the east portal. Cost of utilities relocation and/or support is not included. This is normally a substantial item in cut-and-cover construction. However, as described elsewhere, there is a dearth of conflicting utilities in Waialae Avenue. The utilities cost for both alternatives is the same from First to Seventh; the additional cost to the cut-and-cover alternative east of Seventh is not likely to exceed $2,000,000. The costs stated do not include system-wide components such as trackwork, traction power, fare collection, ventilation equipment, or electrical facilities. Physical space has been provided for line ventilation, but not for station air-conditioning because the extent is currently unknown and is expected to be approximately the same regardless of alternative. Neither are there allowances for contingency nor for escalation because these are basically percentages and would only accentuate the difference.

Evaluation of Cost Estimates

A comparison of cut-and-cover and tunnelling alternatives for subway construction that shows tunnelling to actually cost the least is most unusual. The conclusion is correct, however, because of the circumstances. In U.S. metropolitan areas, subways most frequently are constructed in soft ground. Under such a condition, cut-and-cover excavation is relatively cheap; tunnelling excavation is relatively expensive, and the cut-and-cover alternative, barring excessive utility costs, will be cheaper. As ground conditions improve, the unit cost of cut-and-cover excavation increases while the unit cost for tunnel excavation decreases. In the ultimate case of a massive, unjointed, high strength rock from surface to invert, the unit cost of excavation for the two methods would be approximately the same. The cost of the cut-and-cover box structure will always be significantly greater than the corresponding tunnelled structure because the weight of backfill must be supported by the former. Thus, the geology underlying Waialae Avenue is the reason for the unusual conclusion.

The cost estimates are based on a very brief study. Therefore, the accuracy of the unit prices is of considerable importance. A rudimentary sensitivity analysis of the line construction costs shows that all tunnel costs could be increased 20 percent before the standoff point with cut-and-cover construction would be reached. Alternatively, the tunnel excavation, which accounts for 55 percent of the line tunnel cost, could carry a unit price 40 percent higher than actually used, with other costs held constant, before the standoff point would be reached. On the other hand, cut-and-cover excavation and concrete costs each account for about one-third of the total. The concrete cost is considered reliable and sound. The excavation unit cost, then, would have to be reduced by more than 50 percent, a highly unlikely possibility, before the standoff point is reached. It is concluded, therefore, that any inaccuracy in the unit prices selected is insufficient that correction would alter the conclusion.

The relative station costs are logical. A tunnelled station can be constructed in reasonably competent rock as cheaply as a deep cut-and-cover station, but will cost substantially more than a shallow cut-and-cover station.

The overall cost estimates are, however, suspect on two points. The stations in this study are conceived as spartan, minimal facility structures to move the passengers from street to transit vehicle as cheaply and quickly as possible. Station architects have a tendency to think in terms of big underground space rather than in terms of minimum cost. Accordingly, the cost of the station shells ultimately might be substantially more.

The least justifiable items in the estimates, however, are the unit prices for rock excavation. They are appropriate for the conditions assumed - a reasonably competent, relatively strong rock with frequent, random but discontinous fractures, no extensive weak zones, and no predominating joint sets. The minimal engineering geology data available supports this assumption. Considerable additional subsurface exploration is essential, and the reliability of the cost estimate will increase only as this is accomplished.

IX. CONCLUSIONS AND RECOMMENDATIONS

1. Construction of a subway beneath Waialae Avenue is feasible.

2. After study of both cut-and-cover and tunnelling alternatives, the recommended solution is construction by cut-and-cover methods for the line segment from approximately First Avenue to the Sixth Avenue Station and for the Sixth Avenue Station and construction by tunnelling for the remaining two line segments and the Koko Head Avenue Station.

3. The appropriate portal locations are, for the Ewa portal, offstreet immediately north of First Avenue and, for the Kahala portal, in mid-street east of Seventeenth Avenue.

4. Traffic diversion off Waialae will be difficult because of the lack of a continuous paralleling street to the north and the minimal width of Harding Avenue to the south.

5. The use of twin, single-cell subway boxes and staged construction for the cut-and-cover construction west of Fifth Avenue will permit maintaining partial traffic at all times in that area.

6. Traffic can be diverted both north and south around the Sixth Avenue Station construction site.

7. The general absence of mid-street utilities beneath Waialae simplifies maintenance of essential services.

8. As a result of generally shallow cross-street utilities, the utilities reservation for cut-and-cover construction can be limited to a depth of five feet, unless deeper utilities have been planned.

9. Relocation of the sewer currently housed in the five-by-seven-foot tunnel between Saint Louis Drive and Second Avenue is required. Actual pipe size is unknown but understood to be small. Its invert elevation permits it to cross beneath the cut-and-cover construction at Second Avenue.

10. Available geologic data is minimal, making planning and cost estimating difficult.

11. Six borings taken after drafting of this report provided essential data confirming the feasibility of tunnelling east of Sixth Avenue Station. The borings indicate a great range of rock quality but have not located any extensive zones of very poor rock.

12. The borings indicate the Diamond Head Ash is actually a volcanic tuff with characteristics of a soft to medium rock and, therefore, tunnellable. It quite likely is continuous, less than ten feet thick, and separates the overlying, vesicular Kaimuki basalt from the underlying, denser Mauumae basalt.

13. The use of explosives will be required for either method of construction. Its effect on the community will be minimal where tunnelling is used. Special precautions will be required during cut-and-cover excavation. Careful control of blasting will be required with either construction method.

14. Heavy duty earthmoving rippers can be used for much of the cut-and-cover excavation. However, explosives will still be required for the trench wall trim shots and for the more massive formations in the core of the excavation.

15. Construction of line segments by tunnelling is estimated to cost 20 percent less than by cut-and-cover methods. This is due to the rock mass extending nearly to ground surface.

16. The Sixth Avenue Station, although located between Sixth and Seventh in this report, can be located between Fifth and Sixth without significant adverse effect on the community, traffic diversion, or construction cost.

17. Construction of the Sixth Avenue Station by cut-and-cover methods is recommended. The ability to divert traffic around the site and the minimal to moderate community disruption caused by this method are not considered to warrant the extra cost of a mined station.

18. Construction of the Koko Head Avenue Station by mining methods is recommended. The required depth of the station at this site makes this solution no more expensive than a cut-and-cover station. Use of mining eliminates the very serious traffic diversion and business community disruption problems. The station should consist of two mined caverns, one for each track.

19. Elimination of consideration of system-wide elements, portal construction, contingency, and price escalation in the cost estimate does not affect the relative costs of the two construction methods.

20. A sensitivity analysis indicates the relative cost ranking of the two alternatives is not changed by variations considered likely in the unit costs used.

21. The estimated cost of the recommended alternative is $33 million dollars, exclusive of the elements enumerated in Item 19. The cost of the all cut-and-cover alternative is estimated to be $3 million more.

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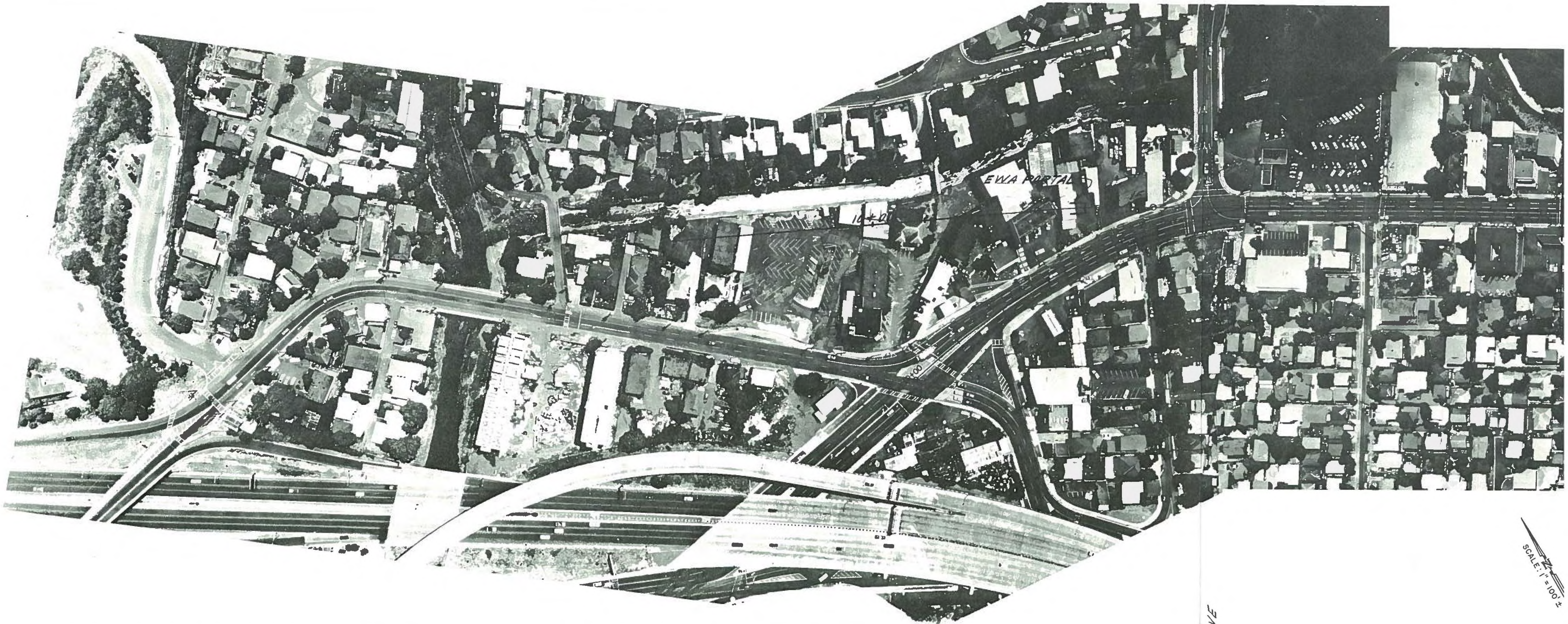

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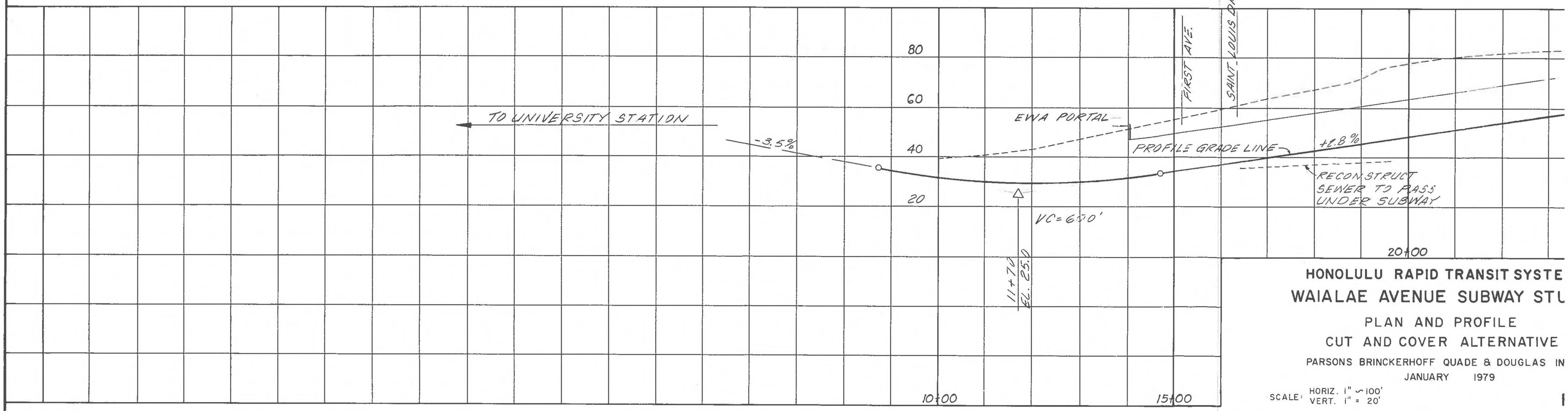

HONOLULU RAPID TRANSIT SYSTE

WAIALAE AVENUE SUBWAY STU

PLAN AND PROFILE

CUT AND COVER ALTERNATIVE

PARSONS BRINCKERHOFF QUADE & DOUGLAS IN

JANUARY 1979

SCALE: HORIZ. 1" = 100' VERT. 1" = 20'

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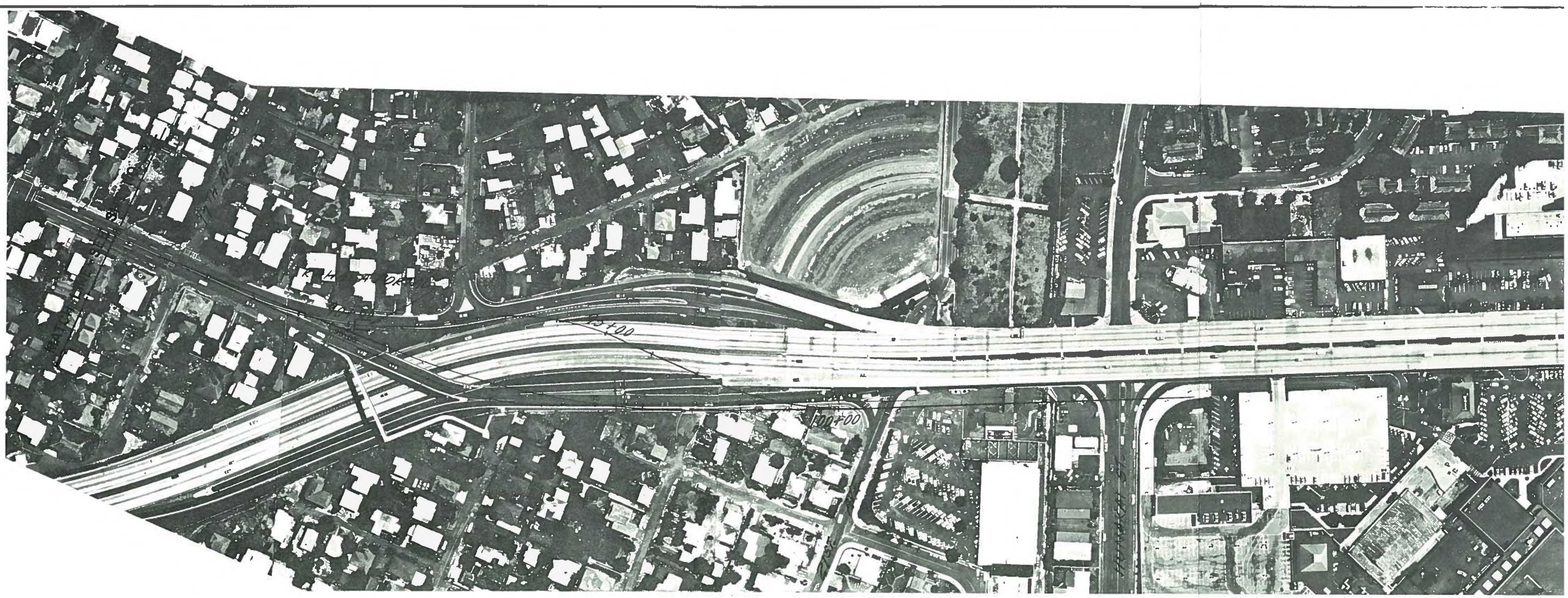

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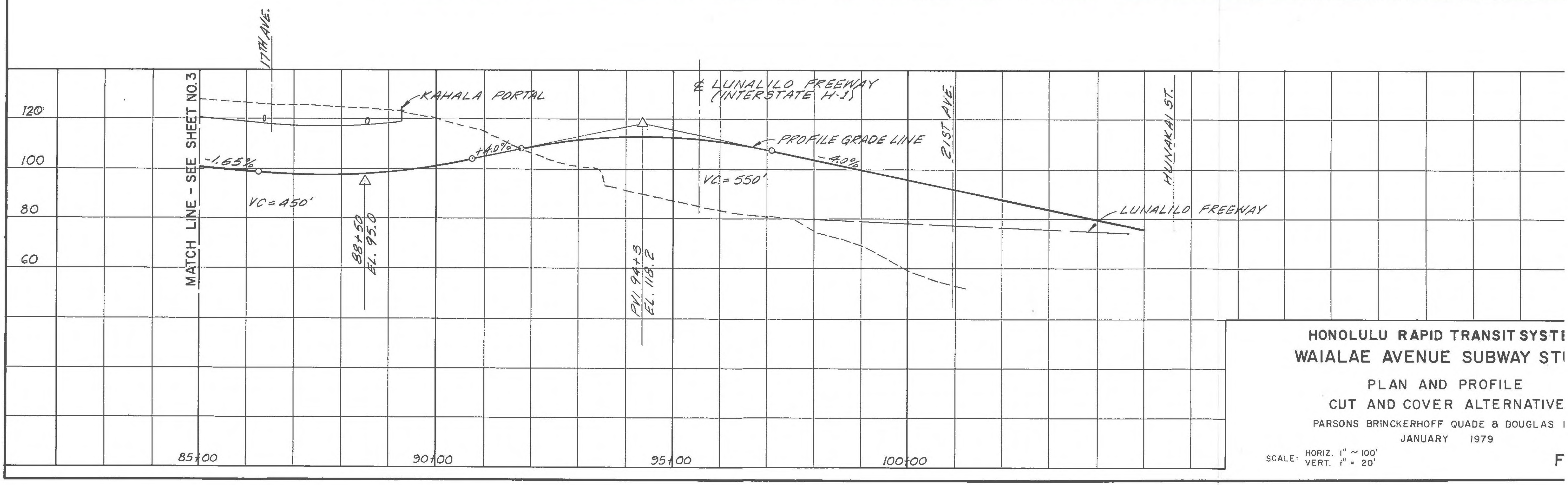

HONOLULU RAPID TRANSIT SYSTE

WAIALAE AVENUE SUBWAY STU

PLAN AND PROFILE

CUT AND COVER ALTERNATIVE

PARSONS BRINCKERHOFF QUADE & DOUGLAS I

JANUARY 1979

SCALE: HORIZ. 1" ~ 100'
VERT. 1" = 20'

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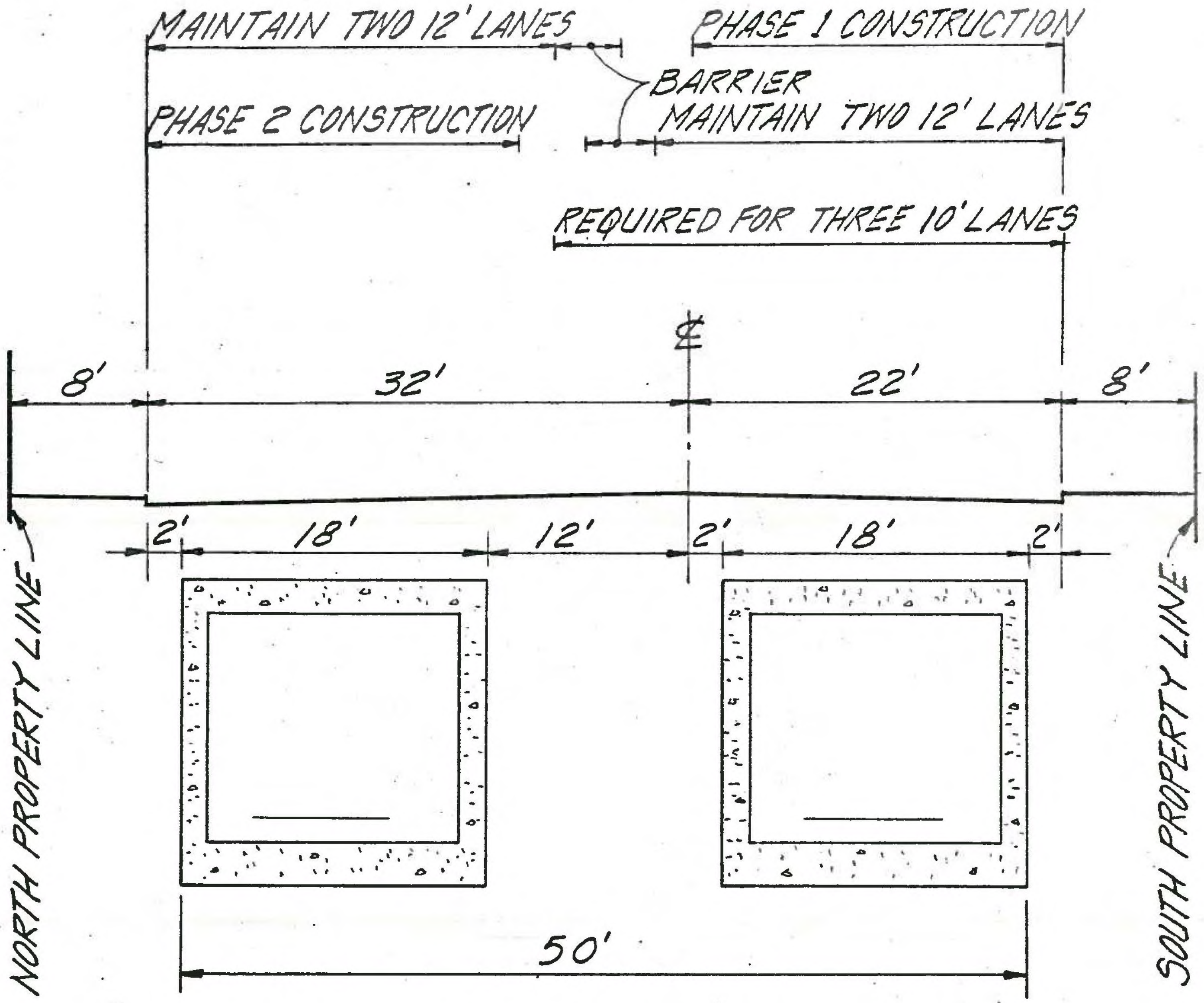

ALL DIMENSIONS ARE APPROXIMATE ONLY.

NOTE: SAFETY, TRAFFIC FLOW, AND WORKING CONDITIONS WOULD BE SUBSTANTIALLY IMPROVED IF THE PLANNED STREET WIDENING (SOUTH SIDE) WERE COMPLETED FIRST.

PROPOSED CONSTRUCTION BETWEEN FIRST AND FIFTH AVENUES

WAIALAE AVENUE SUBWAY STUDY

PARSONS BRINCKERHOFF QUADE & DOUGLAS INC.

FIGURE 5

PLAN
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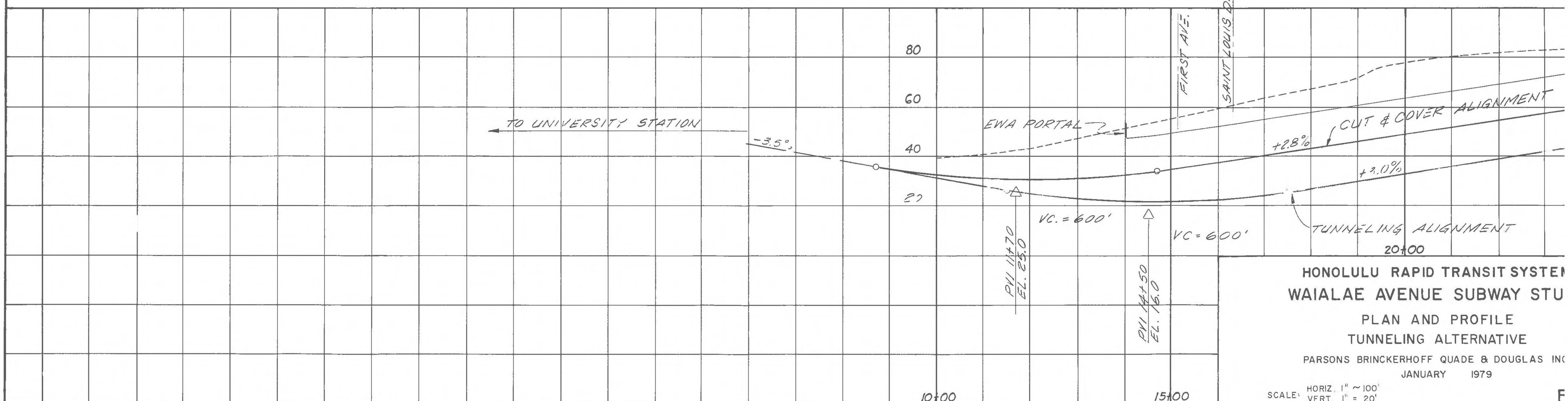

HONOLULU RAPID TRANSIT SYSTEM
WAIALAE AVENUE SUBWAY STU
PLAN AND PROFILE
TUNNELING ALTERNATIVE
PARSONS BRINCKERHOFF QUADE & DOUGLAS INC
JANUARY 1979
SCALE: HORIZ. 1" ~ 100' VERT. 1" = 20'
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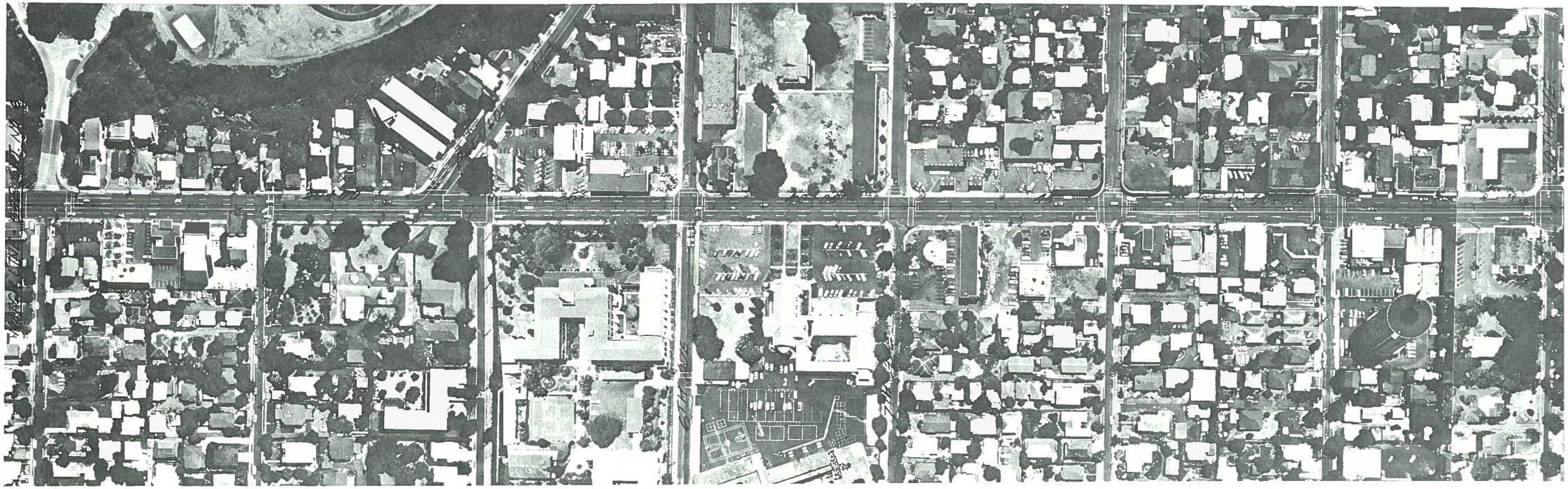

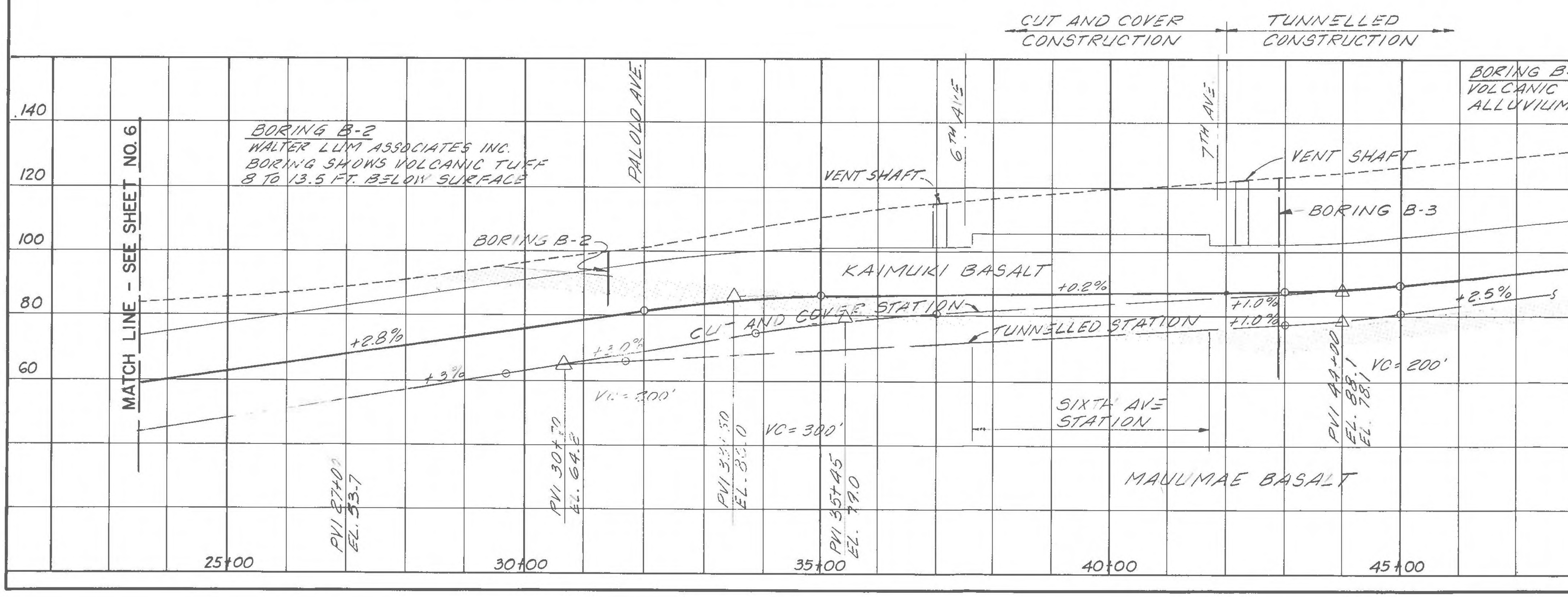

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BY
DATE

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NOTE BOOK
SURVEYED
PLOTTED
GRADES CHECKED
B. M.'S NOTED
STRUCTURE NOTATNS CHKD
NO.
BY
DATE

HONOLULU RAPID TRANSIT SYSTEM

WAIALAE AVENUE SUBWAY STU

PLAN AND PROFILE
TUNNELING ALTERNATIVE

PARSONS BRINCKERHOFF QUADE & DOUGLAS INC

JANUARY 1979

SCALE: HORIZ. 1" ~ 100'
VERT. 1" = 20'

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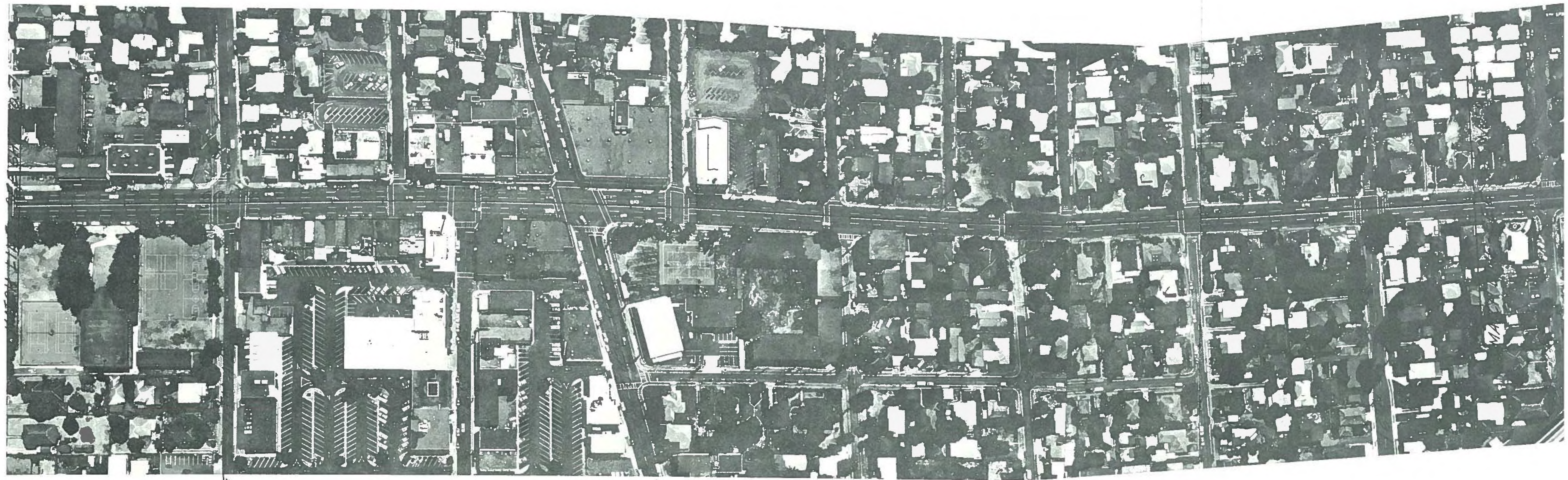

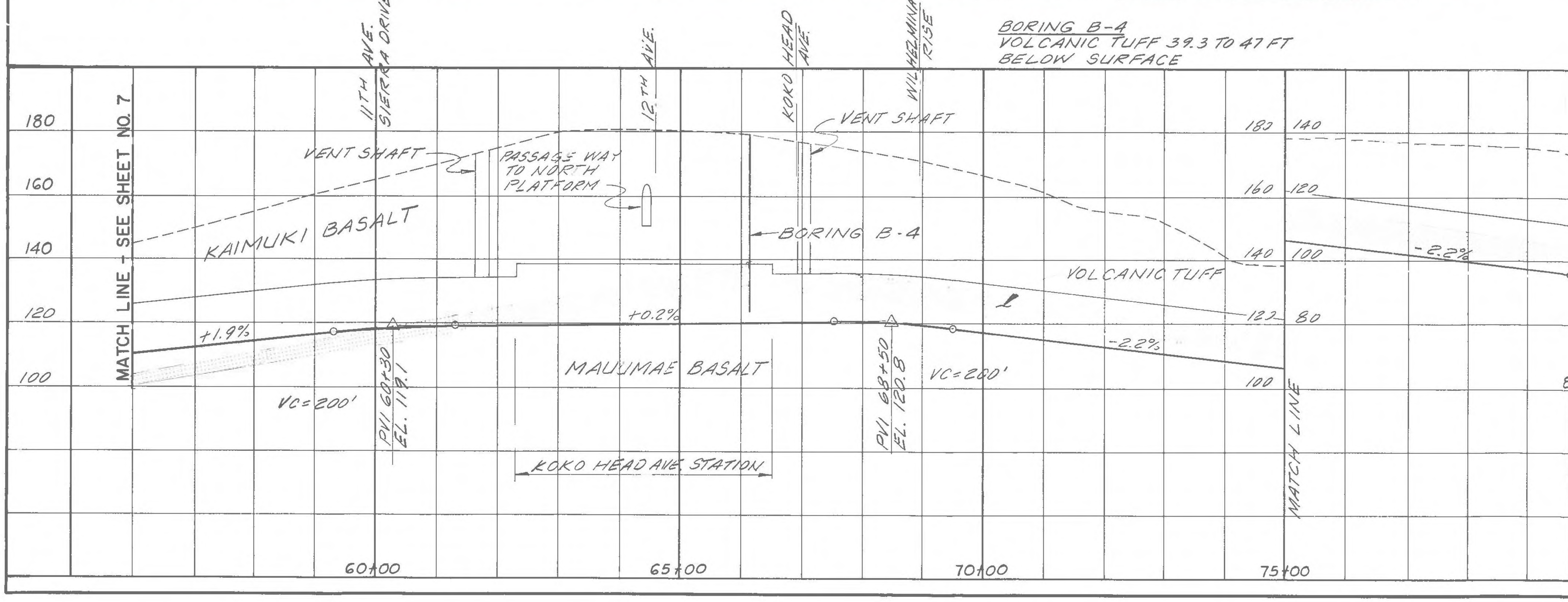

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HONOLULU RAPID TRANSIT SYSTE
WAIALAE AVENUE SUBWAY STU
PLAN AND PROFILE
TUNNELING ALTERNATIVE
PARSONS BRINCKERHOFF QUADE & DOUGLAS IN
JANUARY 1979
SCALE: HORIZ. 1" ~ 100'
VERT. 1" = 20'

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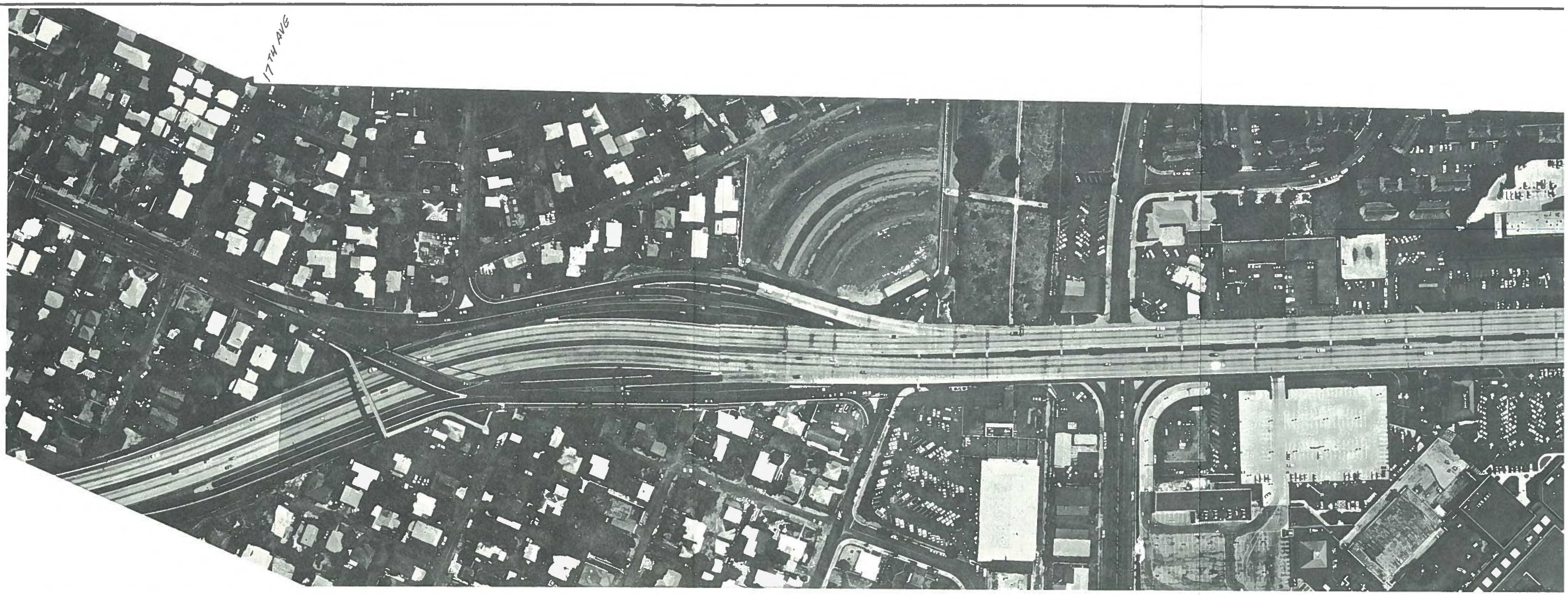

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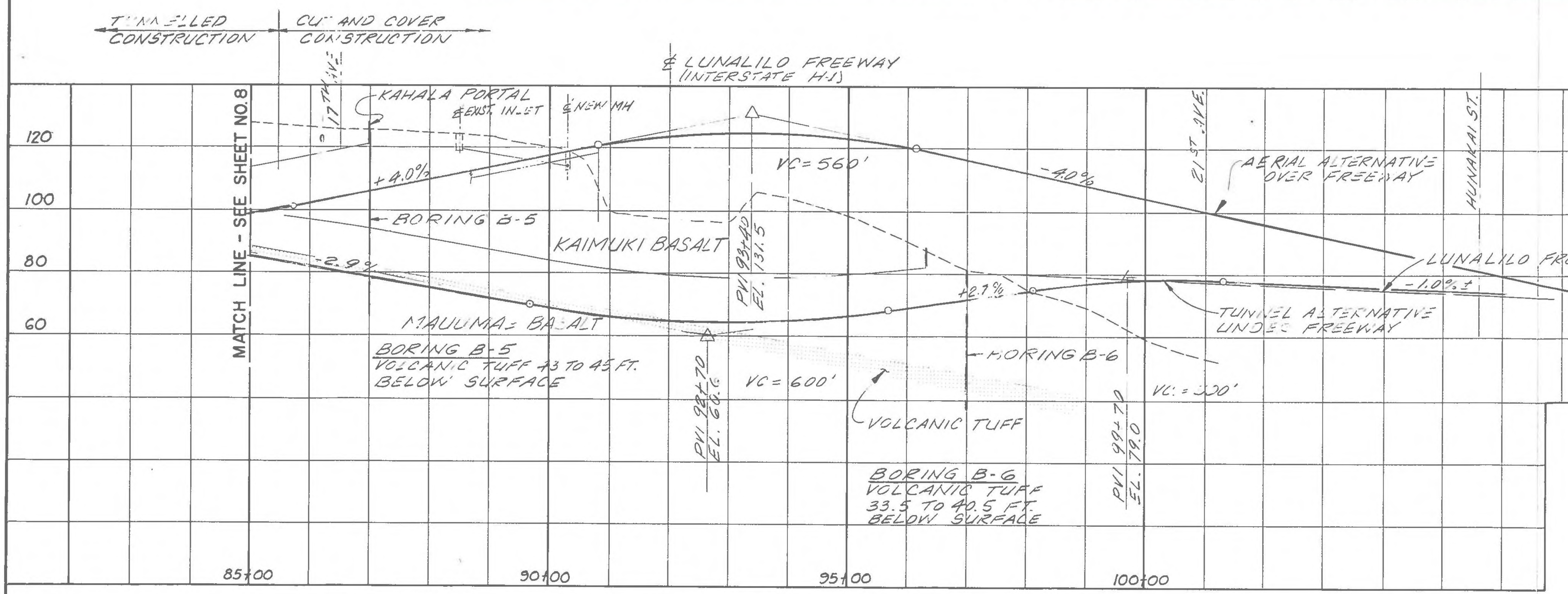

HONOLULU RAPID TRANSIT SYSTE

WAIALAE AVENUE SUBWAY STU

PLAN AND PROFILE

TUNNELING ALTERNATIVE

PARSONS BRINCKERHOFF QUADE & DOUGLAS IN

JANUARY 1979

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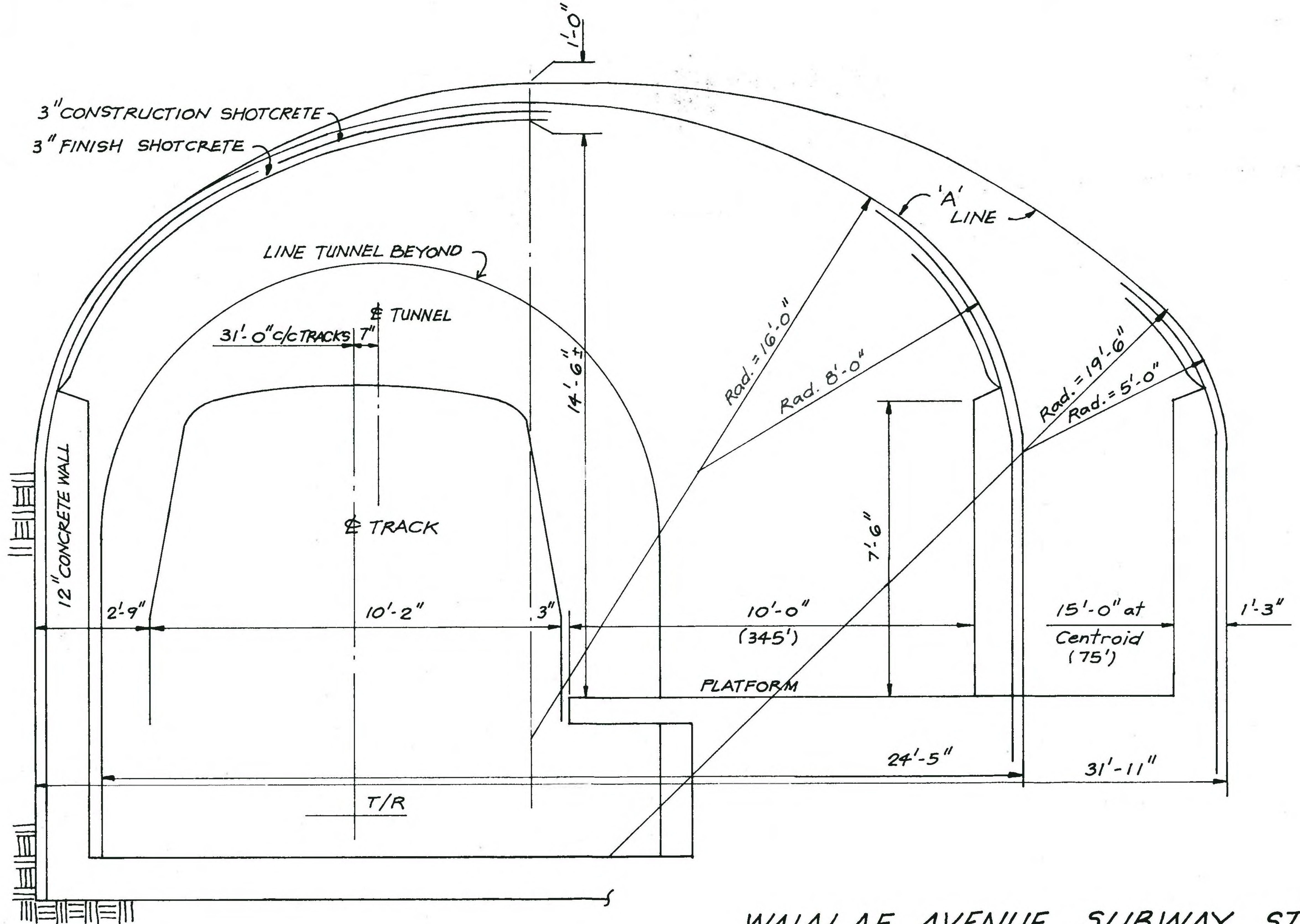
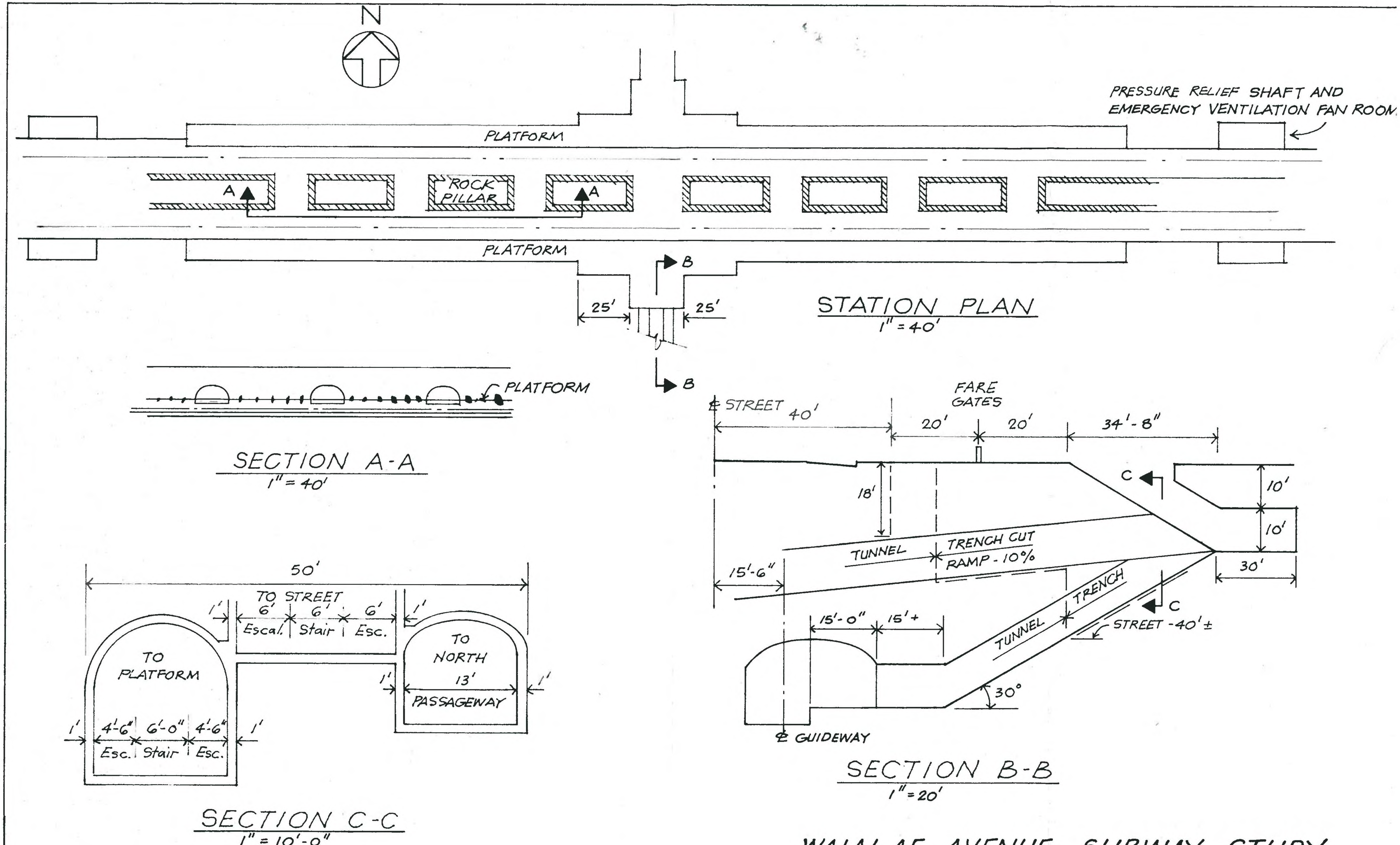


WAIALAE AVENUE SUBWAY STUDY
KOKO HEAD STATION

FIGURE 10

PARSONS BRINCKERHOFF QUADE & DOUGLAS INC.



WAIALAE AVENUE SUBWAY STUDY
KOKO HEAD STATION

FIGURE II

PARSONS BRINCKERHOFF QUADE & DOUGLAS INC.